Development Method for Paralleling Inverters on Microgrid When Islanding Condition Using Reconfiguration of PV Circuit

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***Abstract*-- During islanding conditions, two or more on/off GTIs will work stand alone, these inverters can't work in parallel, because there is no parallel mechanism in this inverter. So power absorption from PV not reach maximum and battery power drain. To make these inverters can work in parallel we must add a power limiter in input inverter using chopping/PWM method and this is not cheap. This research proposed method to parallel two inverter using reconfiguration of Photovoltaic (PV) circuit on microgrid based on/off GTI inverter, in islanding condition, using master slave parallel network topology inverter. The test results showed paralleling two inverter can be done using reconfiguration of Photovoltaic (PV) circuit and increase the absorption of energy from PV up to 26% and reduce the use of battery backup up to 26.38%, so the level of the battery can be sustained.**

***Keyword* : On-off Grid Tie Inverter (On-off GTI), microgrid, parallel inverter, mppt**

I. INTRODUCTION

Environmental friendly renewable energy technologies, such as photovoltaic (PV), and clean and efficient fossil fuel technologies, such as fuel cell and micro-turbine, is the latest generating system which encourages the distribution of power plant technology development, as part of the microgrid. Microgrid is an electrical grid consisting of multiple sources of micro generator (micro source), energy storage systems and loads. All of these components, in grid system/PLN, is seen as an integrated control power plant system [1,2]. Inverters can also work with other micro inverters in supplying power at the same time, in terms of network, which can be seen as one integrated power system. Coordination between micro generator controllers can be done by using the communication network between inverters or without communication network, but it is plug and play integrated, using droop control method, [3,4]. Micro generator with renewable energy sources have problems with the quality of generated power, especially if it is connected to the grid system, where solar power electrical generator would be seen as a negative load by the grid system because it has uncontrolled characteristics related to fluctuations of energy source [5]. Inverter on microgrid system has the ability to operates connected on grid or off grid /islanding [6]. During islanding condition, multiple interconnected micro generator forming a master-slave microgrid architecture[7].

Inverter in power generating systems can be classified into stand-alone inverter systems and grid-connected inverter systems (grid tie inverter/GTI). On a stand-alone system (off grid), the inverter is not connected to the network. On-off GTI can be operated by connecting to the grid or independently supply the local load. In some types, on-off GTI has been equipped with power sharing feature so it can still work in parallel with other inverters during islanding conditions and form a microgrid. However, this type of inverter is expensive which make it less appropriate to apply as a solution to energy problems. At the low end type, on-off GTI has a more affordable price but the problem is that during islanding condition, the inverter only supply local loads that are connected to the inverter, it does not form a microgrid because it doesn't have the ability to share power with other generator. Thus, maximum energy absorption operation cannot be acquired.

So far, the research on control system development of microgrid inverter is focusing on the development of the control system that integrated with operating system of the inverter itself. In this research, there will be do some improvement on inverter operation, which previously failed to operate in parallel between on-off GTI during islanding conditions, so it will be able to work parallel to form a microgrid. Using master slave network topology and re-configuration on PV circuit. By studying the characteristics of on-off GTI when connected in parallel with other inverters when islanding condition and forming microgrid.

II. LITERATURE REVIEW

A. MPPT (maximum power point tracking)

In a grid-connected inverter systems of electric solar power generation, to acquired maximum power, it used the MPPT method. There are several MPPT methods that can be used to obtain proper working voltage suitable to MPP point in order to reach maximum power such as inter-alia, perturb and observe (P&O) and incremental conductance (INC) described in [8,9,10,11].

MPPT is implemented in the GTI circuit based on PV current and voltage measurements[12]. MPPT will generate PWM signals for DC-DC converter series and switching arrangement on the DC-AC converter circuit, it is expected that when connected to the grid, the energy of the sun can be utilized as much as possible to be converted into electricity energy. The amount of the inverter output power at MPP while connected to the grid is,

$$P_{outinv} = \eta \times P_{mpp}$$

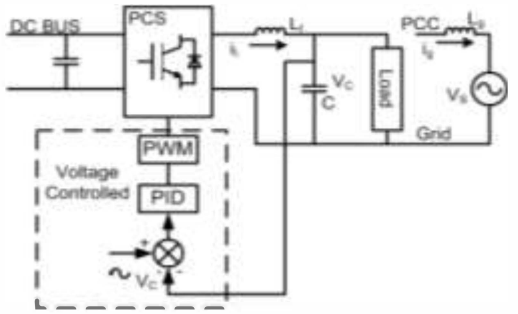
$$P_{mpp} = V_{mpp} \times I_{mpp}$$

Where :

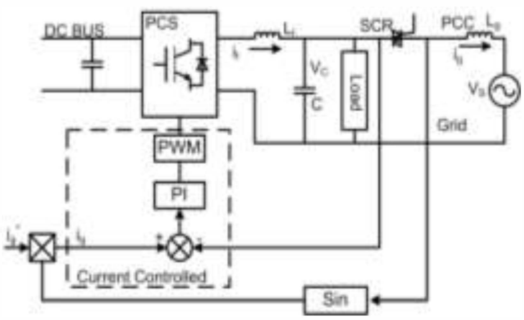
- P_{outinv} , inverter output power
- P_{mpp} , PV output power at MPP
- V_{inv} , PV voltage at MPP
- I_{inv} , PV current at MPP
- η, inverterefficiency

B. On-off Grid Tie Inverter (GTI)

The Inverter topology in off grid and on grid condition can be seen in Fig. 1 [13]. It is shown that in off-grid conditions, PWM reference is based on generating an input signal that formed sine wave and compared with conditions of output voltage. During this condition, the on-off GTI works as a voltage source.



(a)



(b)

Fig. 1. Topology (a) off grid and (b) on grid inverter

Meanwhile during on-grid conditions, the PWM reference refers to the voltage of the grid / network. The inverter works as a current source, using the MPPT mechanism, the power from the source is utilized as much as possible. During transition from off-grid into on-grid conditions, there will be some arrangements to be done on voltage parameter, frequency, phase and references current of the grid. As for the transition from on-grid to off-grid condition, it is affected by grid error parameters condition and a grid setting on voltage and current references [14].

C. Parallel Inverter

In microgrid, The output of each inverter circuit is connected in parallel to supply the load at the same time [15]. Load sharing method in microgrid during islanding condition can be classified into, centralized control, master slave, average load sharing (ALS), circular chain control (3C) [16]. Equivalent circuit of distributed generator using master-slave control configuration during islanding condition can be seen in Fig. 2 [16].

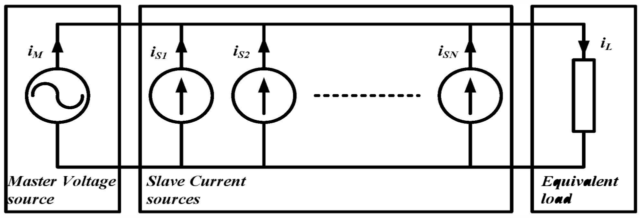


Fig. 2. Equivalent circuit of parallel inverters in distributed generator

In the circuit above, an inverter works as voltage source that serves as temporary master while other inverters work as a current source that serve as slave. Another thing to be concerned when connecting inverters in parallel on a microgrid is the reverse current of the inverter into another inverter. This can be caused by one inverter gives greater power, while the other inverter has a low load. A reverse current can cause damage to the DC link.

III. Experiment Methods

To achieve the goal of this research, an experiment is conducted to test inverter operations of on/off GTI using two 500W on/off GTI and 2 x (4 x 100Wp) PV. Power equation on a stand-alone inverter system can be described by the amount of power input from PV, P_{pv} and the power needed by the load, P_L. Power amount generated by PV is,

$$P_{pv} = V_{pv} \cdot I_{pv} \quad (1)$$

$$I_{pv} = NI_{pvm} \quad (2)$$

Where V_{pv} PV voltage and I_{pv} is the output current of PV module, determined by the number of modules, N and output current each PV module, I_{pvm}. While the magnitude of the load expressed $P_L = V_L\angle\theta_1 \cdot I_L\angle\theta_2$. The relationship between the power at the load against input power PV, $P_L = \eta\, P_{pv}$ where η is the efficiency of PV power against the load, which is affected by the dissipation factor (d_f) of inverter and duty cycle (D) of dc-dc converter of inverter, so it can be concluded that,

$$\eta = (1-d_f)D$$

$$P_L = (1-d_f)D\, P_{pv} \quad (3)$$

D parameters used to arrange so that the PV power is sufficient with the power needs of the load, the amount is $0 < D \leq 1$. The above equation is valid if the battery condition is full or the system does not use a battery and $P_L<P_{pv}$. If the inverter is connected to the battery, the following equation will apply:

For, $P_L<P_{pv}$

$$P_{pv} = P_b + P_d + P_D + P_L \quad (4)$$

$$P_{inv} = P_{pv} - P_b \quad (5)$$

$$P_L = P_{inv} - (P_d + P_D) \quad (6)$$

The above equation applies at the level of battery power (P_{lb}) at the time, $P_{lb} < P_{bmax}$ (maximum power level of the battery), when P_b = 0, then the inverter input power, $P_{inv} = P_{pv}$. The amount of P_b indicates battery charging, P_d inverter power dissipation, and P_D inverter input power are not supplied to the load, when D < 1.

$$P_d = d_f \, P_{inv}$$

$$P_D = (1-d_f)\,(1-D)\,P_{inv}$$

from (5) shows that the amount of PV power that used to supply the battery is determined by how much the rest of the PV power after being used to supply the load.

$$P_{inv} = P_{pv} + P_b \quad (7)$$

$$\text{For } P_L > P_{pv} : P_L = (1-d_f)\,D\,P_{inv} \quad (8)$$

From (7) shows that at the current load is greater than the power generated by the PV then PV power plus battery power is used to supply the load. Power equation for each inverter when connected to a network is expressed by the following equation,

$$\text{For } P_L < P_{pv} : P_{pv} = (P_L + P_d + P_g) \quad (9)$$

$$\text{For } P_L > P_{pv} : P_L = (P_{pv} + P_g - P_d) \quad (10)$$

In (9), when the power on the load is smaller than the input power of PV and by using MPPT mechanism PV will produce maximum power, so that D ≅ 1, it means that almost all of the PV power is distributed to local load and grid.

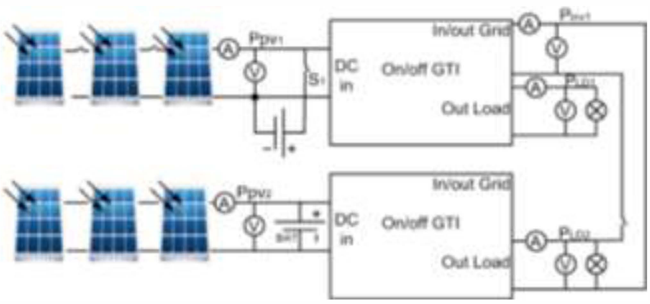


Fig. 3. Circuit of parallel inverter in off grid/islanding

Power equation during islanding conditions is where two inverters are connected in parallel with the master slave configuration, Fig. 3. One inverter works as a master (inv2) and serve as a reference for another inverter operation that works as a slave (invl). In this condition it will apply the following equation,

On condition $P_{L1} + P_{L2} < P_{pv1} + P_{pv2}$ shown on (11), to make the power that is supplied from each generation to meet the load power needs, without going over-supply, particularly from the inverter that serves as a slave, then the amount of power distributed to the load carried with a set number of PV modules (N) that are connected to the inverter by setting the switch that connects the PV circuit.

When, $P_{L1} + P_{L2} < P_{pv1} + P_{pv2}$

$$(P_{L1} + P_{L2}) = (1 - d_{f1})\,D_1\,P_{pv1} + (1 - d_{f2})\,D\,(P_{pv2} - P_{b2})$$

$$= (1 - d_{f1})\,D_1\,V_{pv1}\,N\,I_{pv1m} + (1 - d_{f2})\,D\,(P_{pv2} - P_{b2}) \quad (11)$$

Meanwhile, on the condition $P_{L1} + P_{L2} > P_{pv1} + P_{pv2}$ from (12) shown, there is battery power on the inverter 2, this will happened if the PV power reach its maximum level (the whole PV is already connected) but it can not accommodate load power needs, so power from battery inverter 2 will also supply power to the loads.

When, $P_{L1} + P_{L2} > P_{pv1} + P_{pv2}$

$$(P_{L1} + P_{L2}) = (1 - d_{f1})\,D_1\,(V_{pv1}\,N\,I_{pv1m} + P_{b1}) + (1 - d_{f2})\,D\,(P_{pv2} + P_{b2}) \quad (12)$$

IV. Results And Discussion

On/off GTI in parallel during on-grid conditions is intended to see the power sharing that happened on both inverters. When only one inverter is connected to grid so with a load of 97.5 W and PV input power is only 94.33 W, and then part of if is supplied by the grid of 55.5 W, Table I. This is acceptable in accordance with the applicable equations.

TABLE I. Parallel 2 On/Off GTI When On Grid

P_{DC1} (W)	P_{DC2} (W)	P_{L1} (W)	P_{L2} (W)	P_{pln} (W)
94,33	0	97,5	0	55,5
94.21	94,40	97,2	0	14,2
94.25	94,40	0	0	-82,1
93,17	0	97,1	0	56,3

By parallelizing both inverters during off grid, it shows that at the power needs in inverter 1 is supplied by inverter 2 which acts as the master and inverter 1 as slave. Power absorption in inverter 2 performed optimally. When the power from inverter 1 is reduced, the excess power will flow into the battery. In this test, the battery is connected back to the master. In addition, there is a change in power flow direction, where the excess of power in inverter 1 is supplied to inverter 2, Table II.

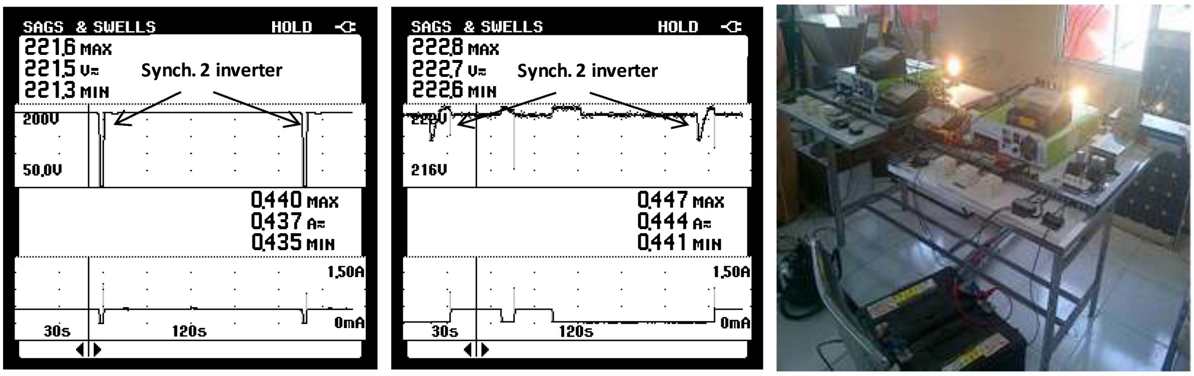
When there is an increase in input power in PV where the power of inverter 1 exceeds power needed by inverter 2/master causing a reverse current on inverter 2, protection on inverter 2 disconnect parallel connection on both inverters, as shown in Fig. 4(a), so that the configuration change to stand-alone operation. Through the reconfiguration of PV circuit by reducing the amount of PV panels on inverter 1, then power equilibrium can be achieved again so that both inverters can work in parallel. Synchronous condition when both inverter work in parallel shown in Fig. 4(b). Test circuit is shown in Fig. 4(c).

V. Conclusion

During off-grid condition, on/off GTI works stand alone to supply power, in this operation mode not all energy from PV is absorbed, especially during low-load and full battery conditions, only 73.47% of the power is absorbed. When paralleled with another inverter with a master slave topology and the same load, the energy absorption from PV is increased to 99.47%. In addition, with this topology energy usage from battery to supply load power during stand alone operation reached 26.38%, while in parallel operation that power requirements can be supplied from another inverter, power sharing occurs, so the use of battery energy can be reduced to 0%.

TABLE II. PARALLEL 2 ON/OFF GTI IN OFF GRID CONDITION

Rad (W/m^2)	Num. PV		PV (DC)		BATT (DC)		INV1(AC)	LOAD (AC)	
	PV_1	PV_2	P_1 (W)	P_2 (W)	P_1 (W)	P_2 (W)	P_1 (W)	P_1 (W)	P_2 (W)
588	4	4	94,34	69,31	14,96	0	0	56,7	14,8
579	4	4	88,82	88,35	0	0	-20,95	56,7	14,8
576	4	4	88,69	88,67	0	15,68	9,89	25,5	14,8
587	4	4	78,10	94,25	0	26,85	0	25,5	14,8
591	3	4	70,98	94,65	0	20,13	-7,12	25,5	14,8
557	3	4	62,66	83,54	0	-30,5	-4,74	14,8	56,7
601	4	4	95,53	95,52	0	14,36	28,13	14,8	56,7



(a) (b) (c)

Fig. 4. (a). Unstable condition of parallel 2 inverter due to reverse current (b). Synchronous condition of 2 stable invertere and achievedstability due to power arrangement.(c) Test circuit of parallel on/off GTI

REFERENCES

[1] R.H.Lasseter, "Micrograids", Power Engineering Society Winter Meeting, 2002. Ieee, Page(S): 305 - 308 Vol.1

[2] Lasseter, A. Akhil, C. Marnay, J. Stephens, J. Dagle, R. Guttromson, A. Sakis Meliopoulous, R. Yinger, and J. Eto, *"Integration of Distributed Energy Resources – The MicroGrid Concept"*. CERTS MicroGrid Review Feb 2002

[3] Lasseter, R.H. ; Paigi, P. "Microgrid: a conceptual solution", Power Electronics Specialists Conference, 2004. PESC 04. 2004 IEEE 35th Annual Vol.6, Page(s): 4285 - 4290

[4] Piagi, P and Lasseter, R.H. "Autonomous control of microgrids", Power Engineering Society General Meeting, 2006. IEEE

[5] Ph. Degobert, S. Kreuawan and X. Guillaud "*Micro-grid powered by photovoltaic and micro turbine*", ICREPQ'06, 2006

[6] Rudy Setiabudy, BS Hartono, Budiyanto, "*Analysis Characteristics of On/Off Grid Tie Inverter and Implementation in Microgrid*", TELKOMNIKA, VOL. 11(3), SEPT. 2013, pp. 441-450 [DOI]: 10.12928/TELKOMNIKA.v11i3.1157

[7] J. A. Peças Lopes, C. L. Moreira, and A. G. Madureira, *"Defining Control Strategies for MicroGrids Islanded Operation"*, IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 21, NO. 2, MAY 2006

[8] Mohammed A. Elgendy, Bashar Zahawi, dan David J. Atkinson, "*Assessment of Perturb and Observe MPPT Algorithm Implementation Techniques for PV Pumping Applications*", IEEE TRANSACTIONS ON SUSTAINABLE ENERGY, VOL. 3, NO. 1, JANUARY 2012

[9] M.Lokanadham dan K.Vijaya Bhaskar, "*Incremental Conductance Based Maximum Power Point Tracking (MPPT) for Photovoltaic System*", International Journal of Engineering Research and Applications (IJERA), ISSN: 2248-9622, www.ijera.com, Vol. 2, Issue 2,Mar-Apr 2012, pp.1420-1424

[10] Nazih Moubayed, Ali El-Ali, dan Rachid Outbib, "*A comparison of two MPPT techniques for PV system*", WSEAS TRANSACTIONS on ENVIRONMENT and DEVELOPMENT, ISSN: 1790-5079, Issue 12, Volume 5, December 2009

[11] Nicola Femia, Giovanni Petrone, Giovanni Spagnuolo, dan Massimo Vitelli, "*Optimization of Perturb and Observe Maximum Power Point Tracking Method*", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 20, NO. 4, JULY 2005

[12] S.Gomathy, S.Saravanan, Dr. S. Thangavel, "*Design and Implementation of Maximum Power Point Tracking (MPPT) Algorithm for a Standalone PV System*". International Journal of Scientific & Engineering Research Volume 3, Issue 3, March -2012, ISSN 2229-5518

[13] Guoqiao Shen, Dehong Xu, dan Danji Xi, "*Novel Seamless Transfer Strategies for Fuel cell Inverters from Grid-tied Mode to Off-grid Mode*", Applied Power Electronics Conference and Exposition, 2005. APEC 2005. Twentieth Annual IEEE, Page(s): 109 - 113 Vol. 1

[14] Zhilei Yao, Lan Xiao, dan Yangguang Yan, "*Seamless Transfer of Single-Phase Grid-Interactive Inverters Between Grid-Connected and Stand-Alone Modes*", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 25, NO. 6, JUNE 2010, page 1597-1603

[15] Chien-Liang Chen, Yubin Wang, Jih-Sheng (Jason) Lai, Yuang-Shung Lee, dan Daniel Martin, "*Design of Parallel Inverters for Smooth Mode Transfer Microgrid Applications*", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 25, NO. 1, JANUARY 2010

[16] Josep M. Guerrero, Lijun Hang, dan Javier Uceda, "*Control of Distributed Uninterruptible Power Supply Systems*", IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 55, NO. 8, AUGUST 2008